JET PROPULSION LABORATORY INTEROFFICE MEMORANDUM

312/96.DTL-30

April 30, 1996

TO: **Sam Dallas**

FROM: **Dan Lyons** 264-214 x 31004

SUBJECT**: MDT Action Item #38: Very Conservative 150 km AB-1 Target**

Mission Design Team Action Item #38 requested an analysis of a very conservative target altitude for AB-1. Memo 312/96.DTL-27 “AB-1 Altitude” recommended an AB-1 target altitude of 135 km (plus maneuver uncertainty) based on a poll of atmospheric experts to determine the highest altitude where the critical density of 143 kg/km^3 might occur. Although the proposed AB-1 target altitude of 135 km contained some built in conservatism since it assumes worst case dust at Mars Perihelion, there is a potential for loss of mission if the Mars Global Surveyor dips too deeply into the atmosphere. Since there is not very much data at the aerobraking altitudes, there is a reason to be very conservative during the Walkin. This memo will try to quantify the tradeoffs associated with targeting AB-1 for an altitude of 150 km.

In memo 312/96.DTL-28 “Critical Scale Height During Walkin”, I developed the idea of the “Critical Scale Height”, h_s*, the scale height that makes the density at the target altitude equal to the critical density. A maneuver is considered safe if the critical scale height is significantly less than the smallest realistic scale height. The Baseline plan (Table 1) was modified to produce a plan (Table 2) which had equal critical scale heights (3.0 km) for remaining walkin maneuvers (AB-2, AB-3, and AB-4). This approach has been applied to some walkin designs which target AB-1 at 150 km.

Table 3 shows that for the same atmospheric model used in Tables 1 & 2, increasing the AB-1 target altitude to 150 km increases the critical scale height to 3.4 km (from 3.0 km for a 135 km target altitude). Since 3.4 km is still much less than the smallest realistic scale height of about 6 km, increasing the AB-1 target altitude from 135 km to 150 km increases the risk by an acceptably small amount.

Although our planned maneuvers may have equal critical scale heights, the actual atmosphere will be different from whatever we plan now. Table 4 shows the walkin for equal scale heights assuming that the 60 kg/km^3 density is at 100 km (rather than at 110 km for Table 3) and the scale height is a constant 6 km. The critical scale heights would only increase to 3.6 km, still well below the 6 km minimum realistic threshold. Unfortunately, we will not know in advance whether the atmosphere is more like that in Table 3 or Table 4. Since we are planning to pick the sizes of the walkin maneuvers during cruise, we will be stuck with a limited number of choices for each maneuver.

Table 1: Baseline Aerobraking Maneuvers .

AB-#	H_o (km)	ρ_o (kg/km^3)	h_o - h (km)	DV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	135	2	18	0.72	4.2	0.011
3	117	20	4	0.16	2.0	0.10
4	113	40	3	0.12	2.4	0.20
Post AB-4	110	60				0.33

Table 2: Aerobraking Maneuvers with Equal Values for h_s*

AB-#	H_o (km)	ρ_o (kg/km^3)	h_o - h (km)	ΔV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	135	2	**12.9**	**0.52**	**3.0**	0.011
3	**122.1**	**11.6**	**7.6**	**0.30**	**3.0**	**0.06**
4	**114.5**	**32.5**	**4.5**	**0.18**	**3.0**	**0.18**
Post AB-4	110	60				0.33

Table 3: Aerobraking Maneuvers with Equal h_s*, 150 km AB-1

AB-#	H_o (km)	ρ_o (kg/km^3)	h_o - h (km)	ΔV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	**150**	**0.168**	**22.7**	**0.91**	**3.4**	**0.0009**
3	**127.3**	**4.72**	**11.5**	**0.46**	**3.4**	**0.026**
4	**115.8**	**25.6**	**5.8**	**0.23**	**3.4**	**0.14**
Post AB-4	110	60				0.33

Table 4: Aerobraking Maneuvers, Equal h_s*, 150 km AB-1, Hs = 6.0 km

AB-#	H_o (km)	ρ_o (kg/km^3)	h_o - h (km)	ΔV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	**150**	**0.038**	**29.5**	**1.18**	**3.6**	**0.0002**
3	**120.5**	**2.93**	**13.9**	**0.56**	**3.6**	**0.016**
4	**106.6**	**22.7**	**6.6**	**0.26**	**3.6**	**0.12**
Post AB-4	**100**	60				0.33

Table 5 shows what happens if we pick our maneuver sizes based on Table 3, but encounter an atmosphere like that in Table 4. The first two planned maneuvers (AB-2 and AB-3) would have much lower critical scale heights which are less than 3. If a maneuver size were available to complete walkin on AB-4 as planned(highly unlikely), then AB-4 would have to lower periapsis from 115.8 km to 100 km with a large critical scale height of nearly 5 km. Assuming that there are a limited number of maneuvers to choose from implies that AB-4 would be the same size as AB-3, such that the critical scale height would only be 3.6 km for an 11.5 km lowering of periapsis rather than 4.9 km for a 15.8 km lowering of periapsis. Of course, additional maneuvers would be required to complete the walkin phase. Assuming that a 0.17 m/s maneuver were available to reach the desired 100 km altitude, AB-5 would require a critical scale height of only 2.9 km. Since we cannot pick the exact size of the maneuvers in response to the observed atmospheric densities, more than one additional maneuver might be required to complete the walkin phase.

Table 5 was generated assuming that the atmospheric density was significantly less than that used to create the plan, so the total change in periapsis altitude had to be larger than for the "plan" in Table 3. An additional maneuver had to be added to keep the critical scale heights reasonably small, i.e. to break the 4 smaller steps rather than 3 larger steps (a larger step means a larger critical scale height, closer to the danger limit). Similarly, if the atmospheric density is greater than the model, so that the total periapsis altitude change to reach the main phase altitude is less than the plan, one might think that the critical scale heights would be smaller for a given number of walkin steps, but this is true only if you are able to pick the sizes of the maneuvers in response to the observed atmosphere. If the density is greater than expected, then the critical scale height is also greater for a given maneuver size, and you may be forced to use the next smaller maneuver size. AB-2 might use the smaller maneuver planned for AB-3, and AB-3 might use the smaller maneuver planned for AB-4, and an additional maneuver might still be required to complete the walkin phase because the "next smaller" predetermined maneuver sizes may not add up to enough altitude change to reach the desired altitude at the end of AB-4. Using predetermined maneuver sizes makes an additional walkin maneuver more likely.

Table 5: Aerobraking Maneuvers, Equal h_s*, 150 km AB-1, Hs = 6.0 km

AB-#	H_o (km)	ρ_o (kg/km^3)	$h_o - h$ (km)	ΔV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	**150**	**0.038**	22.7	0.91	**2.8**	**0.0002**
3	**127.3**	**1.08**	11.5	0.46	**2.4**	**0.006**
4 (to 100 km)	**115.8**	**5.85**	**15.8**	**0.63**	**4.9**	**0.032**
4 (= 3)	**115.8**	**5.85**	**11.5**	**0.46**	**3.6**	**0.032**
5 (ADDED)	**104.3**	**31.8**	**4.3**	**0.17**	**2.9**	**0.17**
Post AB-4	**100**	60				0.33

Table 6: FOUR Aerobraking Maneuvers with Equal h_s*, 150 km AB-1

AB-#	H_o (km)	ρ_o (kg/km^3)	h_o - h (km)	ΔV (m/s)	h_s* (km)	Qdot (W/cm^2)
2	**150**	**0.168**	**18.4**	**0.74**	**2.7**	**0.0009**
3	**131.6**	**2.51**	**11.0**	**0.44**	**2.7**	**0.013**
4	**120.6**	**12.6**	**6.6**	**0.26**	**2.7**	**0.070**
5	**114.0**	**33.3**	**4.0**	**0.16**	**2.8**	**0.18**
Post AB-5	110	60				0.33

Since picking the size of the Aerobraking maneuvers ahead of time will probably require an additional maneuver to complete walkin, and since increasing the target altitude to 150 km has increased the critical scale height to at least 3.4 km, Table 6 shows the maneuvers required to achieve equal critical scale heights assuming an additional walkin maneuver (AB-5). Table 6 uses the same exponential atmosphere as Table 3 (0.168 kg/km^3 at 150 km, 60 kg/km^3 at 110 km). The critical scale height was reduced from 3.4 km to 2.7 km. (The "equalized" critical scale height is approximately 10.5 divided by the number of walkin maneuvers.)

In order to maximize operational flexibility to complete walkin by the end of AB-5, the canned maneuver set should include one larger than planned maneuver ($\approx$ 0.91 m/s). Since the early main phase maneuvers will include a set of very small maneuvers, it may not be necessary to include smaller maneuver sizes as part of the Walkin set, since we can switch to the main phase set at any time during walkin.

Since the heating rate during the main phase is strongly dependent on the duration of the walkin phase, and since an additional maneuver or maneuvers may be needed to reach the altitude at the start of the main phase, it is very important to minimize the number of orbits between maneuvers. AB-1, AB-2 and AB-3 should be performed on consecutive orbits.

Based on the previous analysis for a target AB-1 altitude of 150 km, the following maneuver sizes would provide a reasonable set for Walkin:

Table 7: Candidate Maneuver Sizes for 150 km AB-1 Target Altitude.

ΔV (m/s)	**Δh (km)**	**Comments**
1.00	25	Large. ≈ Average AB-2, Tables 3 & 4
0.75	19	AB-2, Table 6 (Plan for extra "AB-5")
0.45	11	AB-3, Tables 3 & 6
0.25	6	AB-4, Tables 3 & 6
0.15	4	AB-5, Tables 5 & 6. (Largest "Main Phase" ?)

CONCLUSIONS

Targeting AB-1 for 150 km increases the average critical scale height from 3.0 to 3.4 km, which is still much less than the smallest realistic scale height of about 6.0 km.

If the density is less than expected, as shown in Table 4 where the atmosphere is 10 km below that in Table 3, then the critical scale height is increased from 3.4 to 3.6 km, assuming that the maneuvers can be redesigned.

Since the project will be stuck with a limited number of precanned maneuvers, the planned maneuvers may not reach the desired altitude, and an additional maneuver may be necessary. Since the heating rates during main phase are smaller when walkin is shorter, and since an additional walkin maneuver is likely, performing AB-1, AB-2 and AB-3 on consecutive orbits is highly desirable.

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